

Chip Scale Package Integrity Assessment by Isothermal Aging

Reza Ghaffarian, Ph.D.
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2059, Reza.Ghaffarian@JPL.NASA.Gov

Abstract

Many aspects of chip scale package (CSP) technology, with focus on assembly reliability characteristics, are being investigated by the JPL-led consortia. Three types of test vehicles were considered for evaluation and currently two configurations have been built to optimize attachment processes. These test vehicles use numerous package types. To understand potential failure mechanisms of the packages, particularly solder ball attachment, the grid CSPs were subjected to environmental exposure. Package I/Os ranged from 40 to nearly 300. This paper presents both as assembled, up to 1,000 hours of isothermal aging shear test results and photo micrographs, and tensile test results before and after 1,500 cycles in the range of $-30/100^{\circ}\text{C}$ for CSPs. Results will be compared to BGAs with the same the same isothermal aging environmental exposures.

Key words: Chip Scale Package (CSP), Ball Grid Arrays (BGA), isothermal aging, solder ball shear force

Introduction

The popularity of emerging miniaturized Chip Scale Packages (CSPs) is rapidly growing because of their benefits and smaller size, though they may be considered to be an interim solution. There are more than fifty CSPs available from different sources with only a few applications. Implementation will be facilitated as the necessary infrastructure is developed

Emerging CSPs are competing with bare die assemblies and their grid version are the fine pitch version of BGAs. These packages provide the benefits of small size and performance of the bare die or flip chip, with the advantage of standard die packages. CSPs are defined as packages that are up to 1.2 or 1.5 times larger than the perimeter or the area of the die. Many manufacturers now refer to CSP as the package that is a miniaturized version of the previous generation

Figure 1 show grid array and lead CSP categories. Key advantages/disadvantages of each category are also listed. The mini (fine pitch) grid arrays can accommodate higher pin counts, and similarly to BGAs, they have self alignment (centering) characteristics. For BGAs, the ease of package placement requirements has been widely published as one of their attributes. This attribute has permitted reduction in the number of solder joint defects to lower levels than conventional SM packages.

For grid CSPs, the molten surface tensions are much smaller than BGAs since they have lower solder ball volumes. This, coupled with the CSPs finer pitch, can

degrade their self alignment performance, especially with heavy packages. Therefore, the CSPs might require much tighter placement accuracy than the 50 mil pitch BGAs.

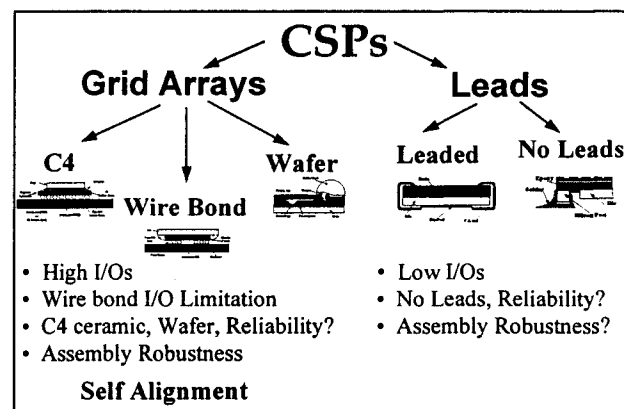


Figure 1: Two Chip Scale Package Categories

This investigation included BGAs as well as grid CSPs to determine degradation of ball/package with temperature and time as well thermal cycling. Other objectives were to determine if there were differences in package/ball interface integrity for different package before and after isothermal exposure and if this correlated with cycles to failure test results. The isothermal temperatures were the maximum thermal cycling temperatures.

BGA Assembly Failure

For grid CSPs, the interface between package and solder balls is a potential failure site. This failure type was observed for plastic BGAs after thermal cycling.

For BGAs, cycles to failure and failure mechanisms under different environments were investigated under another program [1]. Figure 2, adapted from Reference 1, shows cumulative failure percentages versus increasing cycles for several plastic BGA assemblies. Wider distribution for two peripheral BGA packages are evidenced from this figure.

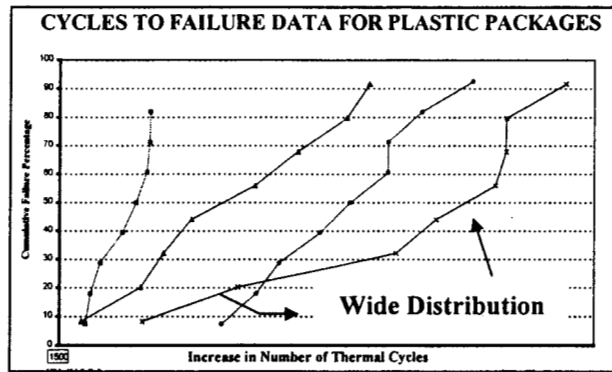


Figure 2 Wide Distribution for Two BGA Package Types

The exact causes of wider distributions are yet to be identified. Possible causes include: PWB materials (FR-4, polyimide), solder volume, and ball/package metallurgy/integrity. Package/ball integrity plays a role since failure analyses of cycled BGA assemblies indicated that failures occurred either at package or board interfaces. In addition, up to 50% reduction in strength were found when another type of BGA build were subjected to isothermal aging for 1,000 hours at 125°C. It was not known this large reduction was an exception because of build configuration or it was true for other widely used BGA configurations.

Test Procedures

Both plastic and ceramic BGAs, which their thermal cycling behavior have already characterized, were subjected to shear testing before and after isothermal aging exposure. The grid CSPs were from the list of leaded, leadless, and grid CSPs which their board assembly reliability are being evaluated by the JPL-led consortia[2].

Both BGA and CSP packages were subjected to visual inspection and scanning electron microscopy (SEM) prior to and after exposure to characterize their joint quality, solder ball metallurgy, and elemental compositions. In addition several assemblies from a grid CSP was subjected to pull test before and after thermal cycling to 1,500 in the range of -30 to 100 °C.

SEM Characterization

Representative SEM photomicrographs of CSP ball shapes and their interfaces are shown in Figure 3.

Photos for a TAB CSP from two suppliers are shown in a and b, and for a wafer version in c. Note differences in interfaces for the same package, but from two suppliers as well as different package categories. The TAB CSP-1 had a pad mask clearance whereas the CSP-2 had a mask non clearance.

Ball Shear Forces and SEM

Figure 4 shows as received cumulative percentage versus shear forces for various BGAs and grid CSPs. The median ranking ($i-0.3/n+0.4$) was used to calculate cumulative percentages. The fifty percentile shear forces as well as their respective shear stresses are shown in Table 1.

Shear forces ranged from 170 to about 400 grams for CSPs and from 1,000 to 1,500 grams for plastic and ceramic BGAs. Shear force depends on many variables including the pad size, metallurgy, and configuration attachment as well as chemistry of solder. Shear force values become critical in mechanical condition.

Shear stresses calculated based on the sheared surface areas had much narrower range for both CSPs and BGAs. It ranged from 3.8 to 5.7 kgmm/mm² except for a grid CSP with value of 7.6 kgmm/mm². This might be due to possibly solder metallurgy as well as ductile failure during shear testing.

It is interesting to note the significant difference in shear forces for different packages. Distributions for the same packages, but different suppliers were slightly different. CSP-2 with a solder a mask non clearance had a tighter force distribution.

SEM photomicrographs for three sheared CSPs are shown in Figure 5. Generally ball/package behavior were ductile in shearing and they were separated from the interface. Two of the balls from the CSP-1 failed in the traces (see right photo of (a)). The non-uniformity in interface failures for CSP-1 might be the reason for this package's wider force distribution plots in Figure 4.

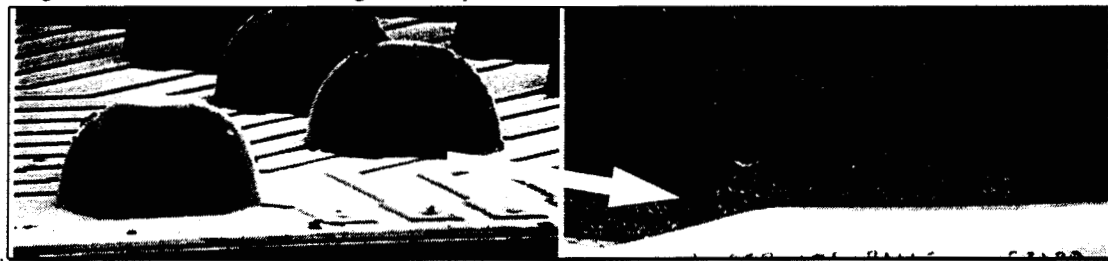
Ball Shear Forces and SEM after Isothermal Exposure

Cumulative shear percentage versus shear force for those exposed to 1000 hours at 100°C are shown in Figure 6. Representative photomicrographs for CSP packages exposed to 500 hours at 125 °C are shown in Figure 7.

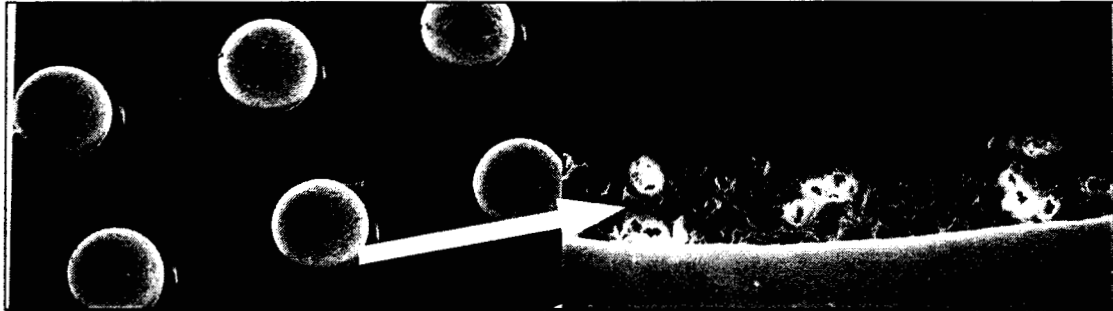
The wafer level package showed improvement after exposure. Most probable cause of improvement after exposure at 100°C is microstructural changes which could have reduced the processing residual stresses. However, improvement after exposure at 125°C is

meaningless since shearing was mode changes from ball/package interface failure to tearing after exposure

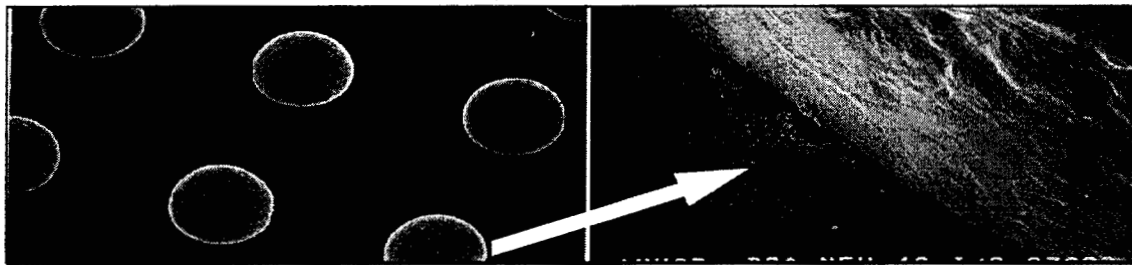
due to significant degradation of package build up.



(a) Wafer Level CSP



(b) TABCSP-1



(c) TABCSP-2

Figure 3 Ball/Package Configurations for Various CSPs

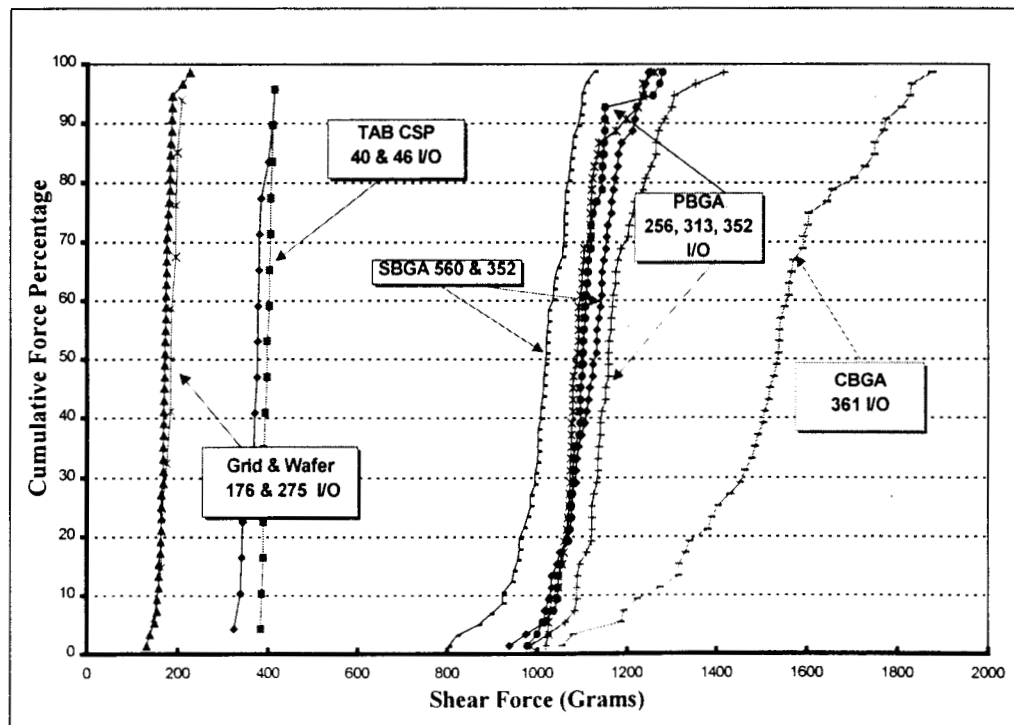
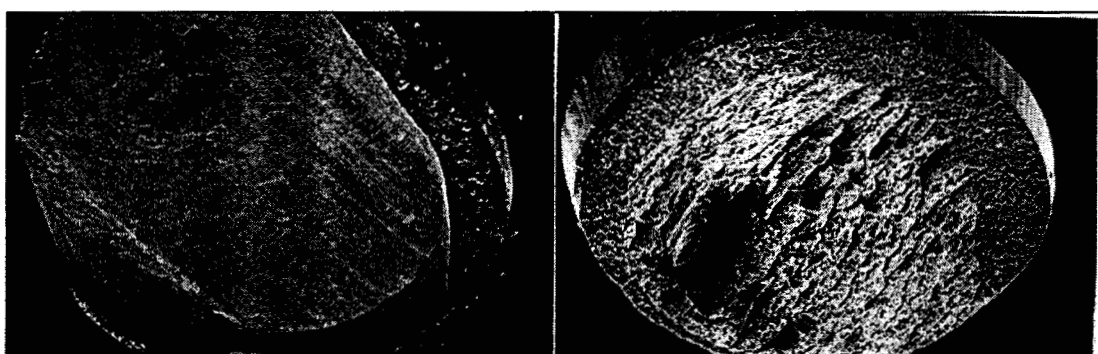


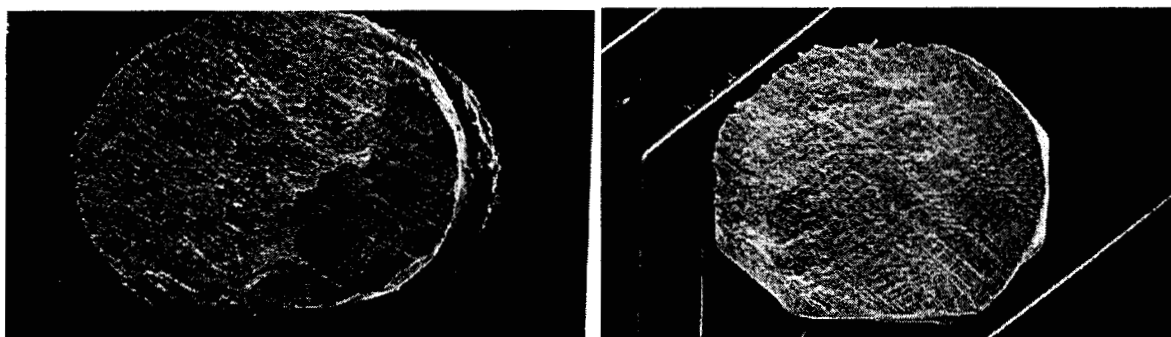
Figure 4 Shear Force Distribution for Various CSPs

Table 1 Shear force and stress for various CSPs

Package Type	I/O	Shear Diameter (mm)	Shear Force (grm) at 50%	Shear Stress (kgrm/mm ²)
TABCSP-1	46	0.320	376	4.7
TABCSP-2	40	0.30	397	5.7
Wafer CSP	275	0.250	185	3.8
Grid CSP	176	0.170	172	7.6
PBGA	256	0.60	1088	3.8
PBGA	313	0.575	1100	4.2
PBGA (OMPAC)	352	0.60	1159	4.1
SBGA	352	0.555	1128	4.7
SBGA	560	0.540	1020	4.5
CBGA	361	0.645	1530	4.7



(a) SEM Photomicrographs of Failure Surface after Shear Test for TABCSP-1



(b) SEM Photos Failure Surface after Shear Test for TABCSP-2 (left) and Wafer level

Figure 5 SEM Photos of Failure Surface after Shear Tests for Various CSPs

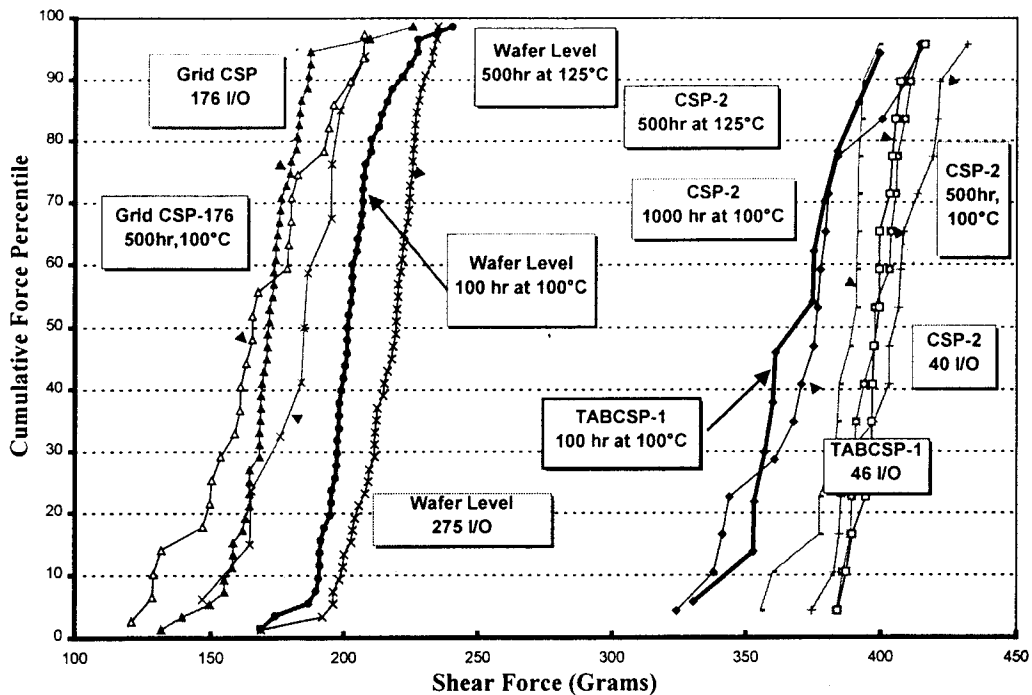
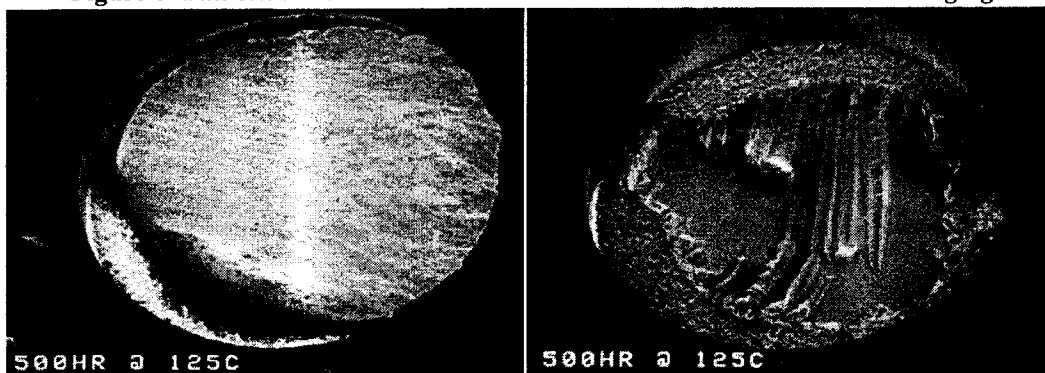
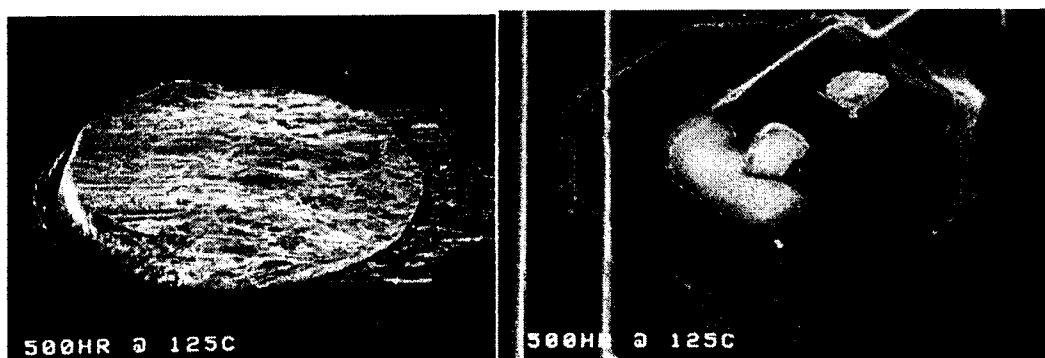


Figure 6 Ball Shear Force Distribution for Various CSPs after Isothermal Aging



(a) SEM Photomicrographs of Failure Surface after 500 hr at 125 °C and Shear Test for TABCSP-1



(b) SEM Photos Failure Surface after 500 hr at 125 °C and Shear Test for TABCSP-2 (left) and Wafer level

Figure 7 SEM Photos of Failure Surface after Isothermal Aging Various CSPs

PULL TEST- AS ASSEMBLED

Several test vehicles were assembled as part of consortia activities for assembly reliability characterization. Four

of the TAB CSP-1 assemblies were subjected to pull test after assembly prior to other environmental tests. The tensile loads were recorded for comparison and detached

board/package surfaces were inspected for failure mechanism. The following were found:

- No solder joint failures were observed; failures were from at the ball/package traces.
- The tensile forces for four assemblies were: 28, 25, 22, and 13 lb. The 13 to 28 lb. for a package of 46 I/Os is equivalent to 128 to 247 g/ball. Shear forces for the same package before exposure to reflow process ranged from 320 to 400 g/ball (see Table 1).

PULL TEST- AFTER THERMAL CYCLING

A number of the assembled test vehicles were subjected to thermal cycling. The cycle ranged from -30 to 100°C and had an increase/decrease heating rate of 2 to 5°C/min and dwell of about 20 minutes at the maximum temperature to assure near complete creeping. The duration of each cycle was 82 minutes. The CSP packages had internal daisy chains which made a closed loop with daisy chains on the PWB enabling the monitoring of solder joint failures through interval electrical resistance measurement. Measurement were performed at room temperature on assemblies removed from thermal cycling chamber. Cycles to failures were recorded.

After 1,500 cycles, several TAB CSP-1 assemblies were subjected to pull testing to determine strength degradation due to thermal cycling. In addition, failure sites and damaged areas were identified by using die penetrant prior to tensile test. The tensile loads for four test vehicles, each with four packages, are listed in Table 2.

Table 2 Tensile forces before and after thermal cycling (1500 cycles, -30/100°C)

TAB CSP-1 46 I/O	Tensile Force As Assembled (lb force)	Tensile Force After 1,500 For 4 TVs (lb force)
A site	25	17*,25,24,23
B site	23	22,18,14,25
C site	13	?,23,18*,20
D site	22	22,18,15,20*
* Daisy chains were open at 1,500 cycles		

Tensile loads ranged from 14 to 25 lb. force which are similar to as assembled tensile test results. No significant decrease in tensile strength indicates that solder joints had minimal degradation due to 1,500 thermal cycles.

Balls failed from ball/package interface within traces. There were no presence of die penetrant on the fractured surfaces, i.e. no solder joint failures. This is a clear indication that failure due to thermal cycling, evident by daisy chain opens for three assemblies, occurred within the package rather than in solder joint commonly observed after thermal cycling. No attempts were made

to narrow the internal failure site since other investigators have identified the failure types for this package [3]. Failures have been reported to be from the TAB lead bond. This is especially might be true only for those fabricated from an early production version. We are also including packages from a more recent production version in our investigation to further substantiate these results.

CONCLUSIONS

- Ball/package failure shear forces were much lower for CSPs than BGAs. As expected, shear stresses (force/area) were about the same for most packages.
- Ball/package joint integrity after isothermal aging exposures depends on package type and aging temperature. Improvements were observed for those aged at 100°C to 1000 hours whereas degradation and failure mechanism changes were observed for those exposed to 125°C.
- Although a few TAB CSP assemblies showed electrical opens after 1,500 thermal cycles (-30 to 100°C), the tensile showed no decrease in strengths. Package internal daisy chain failure due to the TAB lead bond failure was considered to be the possible cause of electrical opens.

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